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DEVELOPMENT OF MULTI CYLINDER CRD-I ENGINE TO MEET EURO VI EMISSION NORMS

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ABSTRACT

Direct injection diesel engine offers the benefit of better fuel economy over gasoline engine. Diesel engine with electronic control of high press ure, multiple injections per cycle, 4valves per cylinder, turbocharged with intercooled, cooled EGR or SCR and DPF have now become the key features to meet the upcoming emissions in India. This paper describes the work done on multi-cylinder diesel engine to meet the requirements of Bharat stage 5 emissions and has the potential to meet Euro6 emission norms. Vehicle simulation model developed by using LOTUS simulation was used to find out the engine steady state speed-load point's equivalent to Bharat stage 5 emission test cycle. Engine emission development was done on test bench using these speed-load points. Engine was optimized with new hardware, namely piston bowl with reduced compression ratio, high capacity EGR cooler and turbocharger to attain the desired emission level. Diesel oxidation catalyst and coated diesel particulate filter (cDPF) loading were optimized to reach Bharat stage 5 emission norms. Vehicle with Selective Catalyst Reduction (SCR) with average 60% conversion efficiency has the potential to meet Euro6 norms.

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1. INTRODUCTION

With the fast rate of depletion of natural resources, fuel prices are ever rising and fuel economy has become the order of the day among vehicle users. On the other hand, critical environmental issues are becoming more and more prominent in the form of phenomena like Global Warming which is apparent from the changing weather patterns.

The automobile sector is largely held responsible in this matter. This poses a bidirectional challenge for the automobile companies. Buyers expect nothing but the highest possible mileage from the vehicles they purchase and are usually the least bothered about environmental impacts. But the Government demands otherwise. Stringent standards have been set to regulate vehicular environmental impact such as the Euro emission norms for the European market and the Bharat Stage emission norms for India. Any vehicle aimed for a particular market must legally comply with the emission norms of that judicial region with little or no tolerance.

Since their very advent, both Euro and Bharat Stage norms have undergone multiple iterations with each subsequent iteration demanding lesser emission of the environmentally unsuitable exhaust components than before. The latest levels, namely Euro-5 and Bharat Stage-5 have been achieved by car manufacturers of respective markets after great deal of brainstorming,

Minimising further scope of improvements. This paper has been produced with an attempt to develop an engine with emission refinement levels which are high enough to comply with Euro-6 specifications. For this purpose, a Compression Ignition engine with Common Rail Direct Injection system has been chosen as it perfectly realises the average customer's demand for efficiency and performance. The methods used for achieving such results have been elaborately stated and explained with necessary proofs in subsequent parts of this paper.

2. EMISSION NORMS

With evolution of the world and growing awareness in society humans have now focused on the problems that arise due to the by-products formed by the combustion of fossil fuels. Governing bodies were set up which conducted experiments to setup norms which could be used as global standards for automobile engineers and industries all over the world. With advancements of technology the norms are being made stricter to make it more eco –friendly. The main concerns of the present are carbon monoxide emissions, particulate matter emissions and nitrous oxide emission (NO_x). The carbon monoxide emissions are taken care of very easily but the main problems being faced are that with the NO_x and particulate matter trade off as increase in one causes the decrease of the other. So multiple after treatment systems are being incorporated in the system to take care of both the emissions one by one and so to meet the stringent EURO VI norms.

Table 1. Bharat stage 4 and 5 and Euro 6 Emission Norms for Passenger vehicle

Emission Norms	CO (mg/km)	HC+NOx (mg/km)	NOx (mg/km)	PM (mg/km)	PM number (Nb/km)
BS4	740	460	390	60	NIL
BS5	740	360	280	5	6 x 10^11
%	No change	22	28	93	PM count
Euro6	740	215	125	4.5	6 x 10^11

Fig. 1. Test bench setup for experimental engine

3. ENGINE SPECIFICATIONS

Specifications	Benchmarked Engine	Modified Engine
Bore (mm)	85.4	85.4
Stroke (mm)	96.0	96.0
Total engine displacement (L)	2.2	2.2
Connecting rod length (mm)	129.8	129.8
Pin offset (mm)	0.60	0.60
Compression ratio	15.2:1	16.5:1

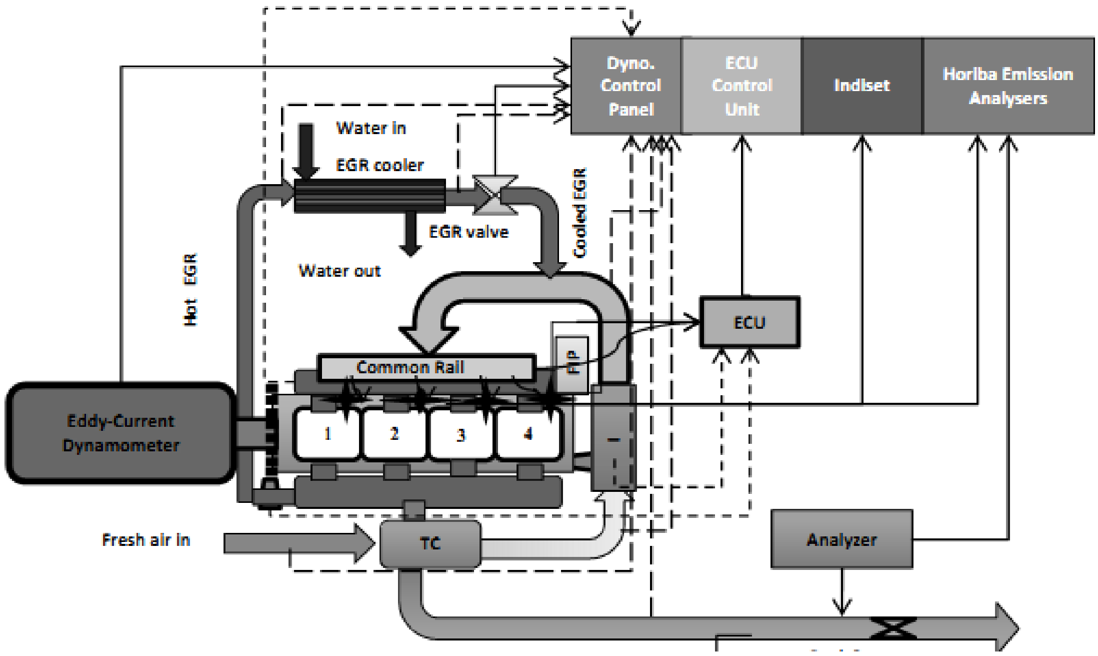
4. PROPOSED METHOD

From the table 1, it can be seen that a reduction of about 46% in NO_X and 96% in PM emissions is required to meet Euro 6 emissions. The two most effective methods of reducing NO_X emission are cooled Exhaust Gas Recirculation (cEGR) and Selective Catalyst Reduction (SCR). Between the two, the cEGR method became more popular because of its ease of design, adaptation and control. Initially the automotive engine was designed for hot EGR to control NO_X emissions. However, there was a limitation of NO_X-PM trade-off with hot EGR. Cooled EGR became more popular due to its better NO_X and PM trade-off. Cooled EGR has become a universal solution for much less NO_X and PM trade-off where there is no possibility of urea infrastructure available for SCR as an alternate solution. The SCR method, on the other hand, is less popular, because it involves high cost and more calibration effort. In cylinder particulate matter can be reduced by effective utilization of air swirl motion in piston bowl by maintaining fuel spray hitting the plane below the bowl throat, increase in rail pressure, optimization of pilot quantity, its separation and main injection timing. However, they cannot reduce the in-cylinder particulate matter to the extent of meeting BS5 requirements without after-treatment system. Reduction of particulate matter by more than 98% is possible by using (cDPF) catalysed particulate filters.

A). Compression Ratio

Base engine compression ratio of 16.5:1 has been modified to 15.2:1 compression ratio without affecting starting of the engine in cold condition and cylinder peak firing pressure below limit of 160 bar. The

Compression ratio has been modified by scaling the 16.5:1 combustion chamber. The reduced compression ratio lowers the end compression temperature, reduces pumping losses and also reduces compression work.



B). Seven Point Injector

The selection of the injector is purely based on the spray-bowl swirl matching with 40 to 50% of hitting plane from the top face of the piston. Six holes injector has been replaced with seven holes and the spray cone angle changed from 148 to 152 degrees to hit spray in new piston crown at 40% of bowl depth with optimized main injection timing for effective utilization of air and fuel mixing as shown in Fig. 2. Injector protrusion was adjusted such that its spray will hit below the bowl radius of the combustion chamber to avoid wall impingement.

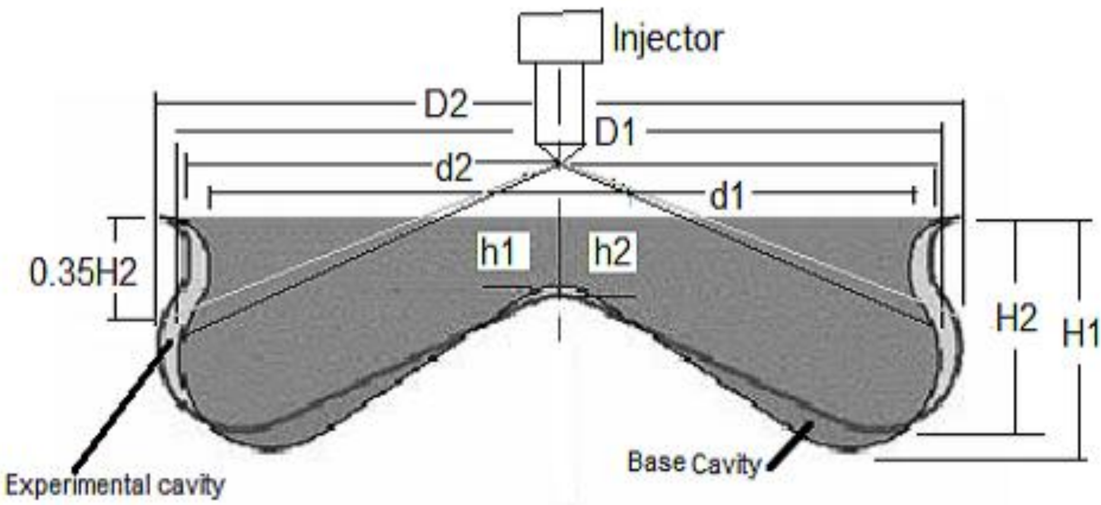


Fig. 2. Piston crown and injector spray comparison of base and experimental engine

C). Turbocharger

VGT turbocharger with generation 3.5 (lower cartridge assembly weight by 2% and ‘S’ shape turbine vane in place of straight vane) was matched to meet higher air flow and boost pressure requirement over a wider range of load and speed conditions. This has helped in adjusting air excess ratio at various operating conditions of engine.

D). EGR Cooler

The EGR is a prime technology for reducing NO_X emissions. Adapting the cooler in the EGR path further reduced the NO_X emissions by lowering the combustion temperature. EGR cooler capacity was increased from 4.5 kW to 10 kW for effective cooling of EGR gas and provision of uncooled exhaust gas in certain operating conditions. Refer to Fig. 3 for a comparison between base engine EGR system and experimental engine EGR system.

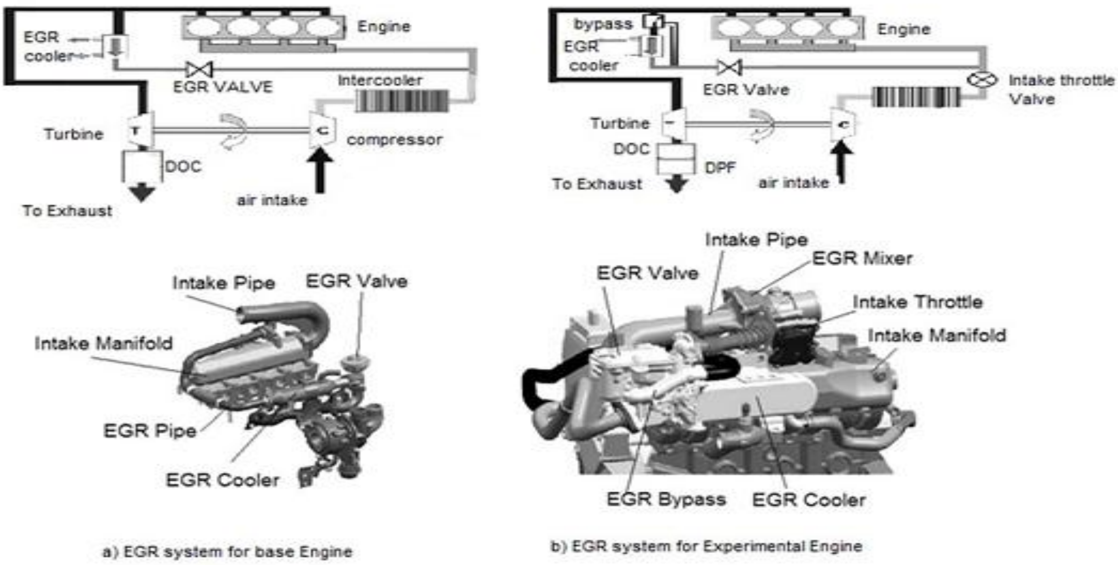


Fig. 3. EGR System layout of base and experimental engine

E). EGR Mixer

EGR mixture was used in intake pipe to improve mixing of exhaust gas with air and to maintain uniformity of the mixture from cylinder to cylinder. This enabled 94% achievement of the uniformity index. Intake throttle was introduced to increase and control EGR rate effectively.

F). Diesel Oxygen Catalyst

Diesel oxidation catalyst was replaced with single canned diesel oxidation catalyst and catalyzed silicon carbide (SIC) particulate filter, which were fitted in a closed couple to the engine. Loading of coating was optimized during engine testing on test bed and on chassis dynamometer.

G). Diesel Particulate Filter

The DPF (Diesel Particulate Filter) removes the slightest amount of particulate matter which remains in the exhaust gas after combustion of the fuel by the common rail system. There are many small cells with a diameter of three hundredths of a millimetre (less than 1.2 thousandths of an inch) inside the filter. These cells trap particulate matter contained in the exhaust gas as it passes through them. After a

certain amount of particulate matter is collected, it is burned by applying heat. To assist with this combustion, the filter is coated with a catalyst. Catalysts are substances which speed up a chemical reaction. The filter removes and cleans more than 90% of the particulate matter contained in the exhaust gas.

H). Selective Catalytic Reduction (SCR)

There are two primary ways to reduce exhaust emissions from diesel engines

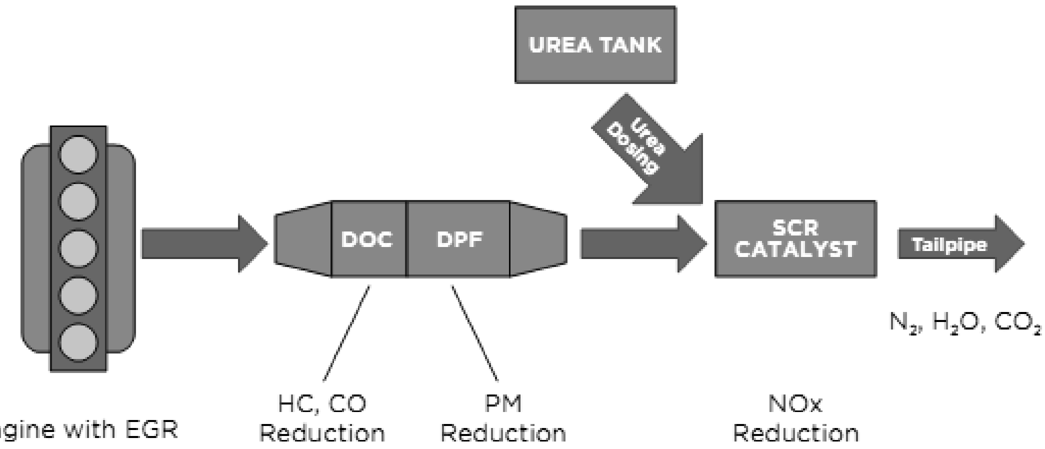
1. Implement in-engine technologies to reduce engine out emissions and,
2. Implement after treatment technologies to clean up the exhaust after it has left the engine but before it is emitted to the atmosphere.

When implementing in engine technology, there are also generally trade-offs among NO_X emissions, PM emissions and efficiency. Approaches that reduce PM emissions within the engine increase efficiency, but also tend to increase peak combustion temperatures and therefore increase NO_X emissions. Approaches that reduce peak combustion temperature lower NO_X emissions, but tend to increase PM emissions and reduce engine efficiency.

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2$

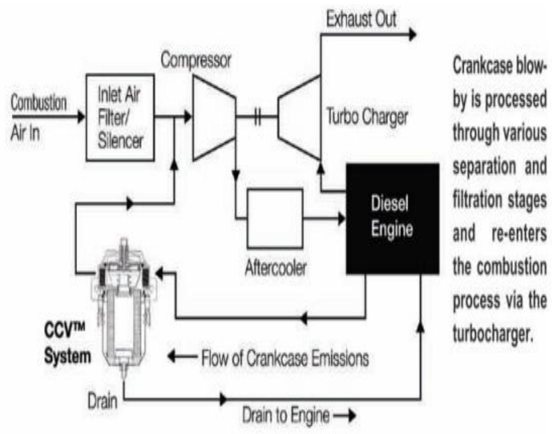
SCR uses a liquid reductant, in conjunction with a reduction catalyst, to reduce nitrogen oxides in diesel exhaust to elemental nitrogen. For mobile applications the reductant is usually a mixture of 32% urea (by weight) in water. The SCR reductant catalyst sits in the exhaust steam, and the urea solution is injected into the exhaust ahead of the catalyst as illustrated in the figure below.



I). Closed Crankcase Ventilation

Closed Crankcase Ventilation (CCV) or Filters (CCF) systems are designed to return crankcase blow-by gases to the engine intake for subsequent and more complete combustion during the combustion process. CCVs can be very cost effective at reducing a vehicle's Particulate Matter (PM) emissions. Properly installed and maintained CCV crankcase controls in both original equipment and retrofit applications have performed effectively in on-road and off-road applications. If however, the disposable filter is not replaced at the appropriate interval, the filter can clog, and this can cause pressure build-up in the crankcase and can lead to crankcase seal leakage and possible reduction in engine performance. Units need to be sized

according to the engine's parameters. The potential CCV purchaser should consult the EPA or California Air Resources Board (CARB) for a list of CCVs that have been verified for use through those agencies' respective testing programs. The cost of the retrofit CCV emission control product is in the range of $450 and the costs of the verified CCV/DOC system ranges from about $1,200 to slightly over $2,000, depending on the engine application and the number of units sold under a given purchase order. Installation costs are typically charged on an hourly basis. The closed crankcase ventilation system can be used on four-cycle, non-EGR, medium-heavy and heavy-heavy duty diesel engines. CCVs can be used with ULSD, conventional diesel, and biodiesel fuels.



J). Denoxtronic

The limit values for harmful emissions are becoming ever stricter. In order to meet these standards, an exhaust gas treatment system is required alongside the cleanest possible fuel combustion. The BOSCH Denoxtronic system, for example, reduces nitrogen oxide emissions in commercial-vehicle diesel engines by up to 95% in combination with an SCR catalytic convertor (SELECTIVE CATALYTIC REDUCTION), converting them into nitrogen and water instead. Using this technology, commercial vehicles can also meet EURO VI emissions standards, which are currently the strictest in the world. A major component of the modern SCR (Selective Catalytic Reduction) systems is the BOSCH Denoxtronic reduction agent metering system .It reduces nitrogen oxides in exhaust gas and has been used in Heavy Commercial Vehicles in Europe since 2004.

Denoxtronic features modular construction and consists of

1. Supply module
2. Dosing module
3. DCU (Dosing Control Unit)

Denoxtronic introduces the reducing agent AdBlue into the exhaust gas flow. AdBlue is administered in the required quantity-precisely adjusted to the current operating status.

Benefits

- Reduction of NO_X emissions to adhere to global emission norms.
- Fuel saving engine design.
- Proven robust technology.
- Controlled by ECU (Electronic Control Unit) or separate DCU.

With Denoxtronic, BOSCH offers a diesel fuel metering system for the regeneration of particulate filters especially for heavy commercial vehicles. The system allows the particulate filter to be regenerated thanks to a targeted injection of diesel fuel into the exhaust gas. An expensive coating for the filter or an additional additive tank are not necessary.

Denoxtronic is integrated into the low-pressure fuel circuit. It injects an exact metered quantity of diesel without compressed air support into the exhaust pipe above the oxidation catalytic convertor. The exhaust gas temperature therefore increases to 600^0C when flowing through the oxidation catalytic convertor. At this point, the soot stored inside in the particulate filter burns off. The flow rate is varied according to the current requirements. The robust and completely maintenance-free system controls the fuel addition as required and independent of the engine injection system.

K). Use of Bosch CRDI Technology

The main technique employed for reducing the overall emissions to the extent of complying with Euro VI norms is increasing the pressure of the Common Rail system. This can be achieved by incorporating certain components provided by BOSCH, namely CRSN 4.2 (fuel pump), CRIN 4.2 (high pressure pump) and LWRN 4.2 (common fuel rail). The pressure of fuel injection can be escalated to values as high as 2400bar using these components which are specific to the Common Rail system.

L). Engine Friction

A relatively minor modification was done on the piston rings to reduce friction in the cylinder-piston pair. Piston top ring tension was reduced by 5%. Oil control ring contact area was reduced to 13%. Due to these changes, engine frictional torque was reduced to 3 Nm at 1000 engine rpm and 5 Nm and 3750rpm. Reduced engine friction has benefited in 0.2% BSFC reduction.

5. ENGINE PERFORMANCE OBTAINED

The compression ratio was changed and we observed that power and BSFC change whereas rest parameters remains unchanged. A comparative study was made for compression ratios 15.2:1 and 16.5:1.

Following results were obtained and a comparison was drawn

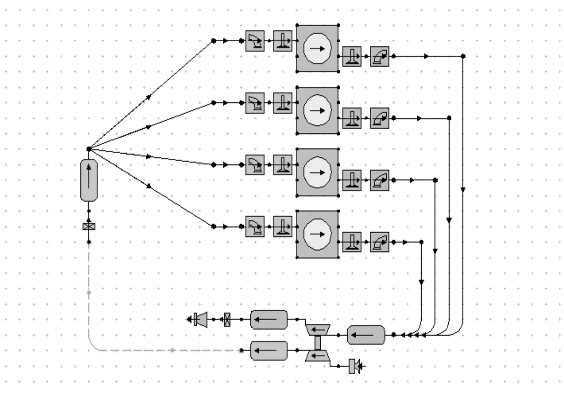
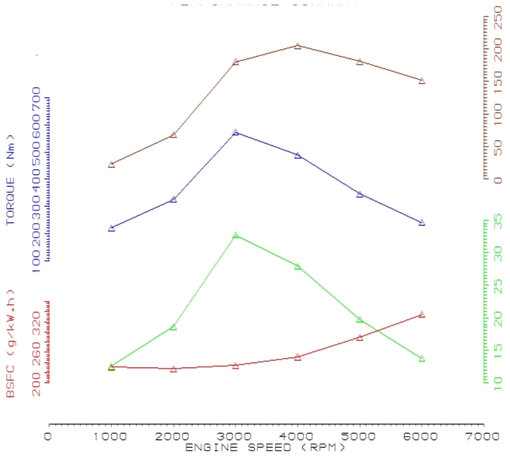


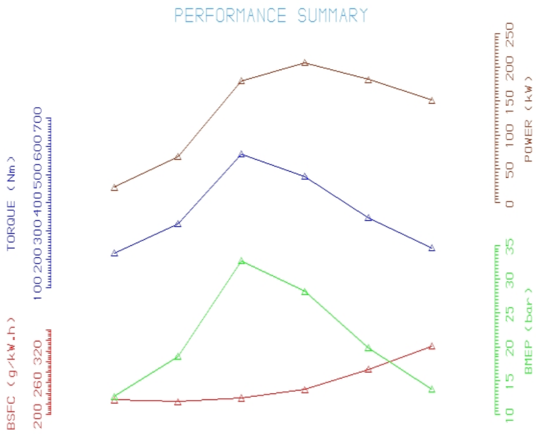
Figure Engine Block Diagram in LOTUS

Parameter for Compression Ratio 15.2:1



Engine Speed (RPM)	Bsfc (G/Kw.H)	Bmep (BAR)	Torque (Nm)	Power (Kw)
1000	231	12.6	220	23
2000	228	18.6	326	68
3000	235	32.7	572	180
4000	251	27.9	489	205
5000	290	19.7	345	181
6000	334	13.8	241	152

Parameters for Compression Ratio 16.5:1



Engine Speed (RPM)	BSFC (G/Kw. H)	Bmep (BAR)	Torque (Nm)	Power (Kw)
1000	228	12.7	222	23
2000	225	18.6	325	68
3000	232	32.7	572	180
4000	247	28.2	493	207
5000	285	19.9	347	182
6000	330	13.7	241	151

6. CONCLUSION

Engine design and development are complex processes. Use of engine simulation software tool would be helpful in early prediction of engine performance and in selecting the operating speed and load points for optimization. Good correlation was noticed between steady state engine bench and chassis dynamometer in terms of NOx,

PM and CO emissions. However, due to changes in engine warm-up conditions between steady state and chassis dynamometer tests, CO and THC emissions were not close to the steady state. In-cylinder optimization of NOx-soot trade-off, turbocharging, common rail with flexible injection control, cooled EGR, diesel oxidation catalyst for CO and THC control and particulate control require diesel particulate filter to comply with BS5 emission norms, and SCR for BS6 / Euro 6 emissions.

6. ABBREVIATIONS

BS4	Bharat Stage 4 Emissions
BS5	Bharat Stage 5 Emissions
cEGR	Cooled Exhaust Gas Recirculation
EGR	Exhaust Gas Recirculation
cDPF	Coated Diesel Particulate Filter
DOC	Diesel Oxidation catalyst
NOx	Oxides of Nitrogen
CO	Carbon Monoxide
THC	Total Hydrocarbon
PM	Particulate Matter
NEDC	New European Driving Cycle
CR	Compression Ratio
VGT	Variable Geometry Turbocharger
INCA	Integrated Calibration and Acquisition
DOHC	Double Overhead Camshaft
HSDI	High Speed Direct Injection
Pt	platinum
Pd	palladium
SCR	Selective Catalyst Reduction
Rpm	revolution per minute

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